Memo

date: *March 20, 2014*

to: *RSC*

from: *D. Beavis*

subject: *CeCPoP Beam Test*

Motivation

The Coherent electron Cooling Proof of Principle (CeCPoP) has requested to conduct tests with the superconducting gun and the buncher cavities during RHIC run14. These are preliminary tests that would be initially operated as RGDs when there is no beam from the gun. If the effort completes sufficient testing of the gun and cavities CeCPoP would like to test the gun and bunchers with low power beam. A test beam requires an exemption from having an ARR in order to conduct it before the end of the RHIC run. The gun requires the RHIC cryogenics system to be operating so the next opportunity to test the gun with beam would be during the next RHIC run, approximately six months later.

The beam test has been proposed to be conducted at low power. The shielding at IR 2 is designed to handle beam faults of the RHIC Proton and ion beams. It will be shown that the shielding is sufficiently thick to allow the CeCPoP to conduct beam tests to full power without any radiological consequences outside the shielding. Although the project has not requested full power testing, this analysis demonstrates that there is no reason to require low beam power for radiological protection purposes.

Machine Characteristics

Some simple parameters for the test are:
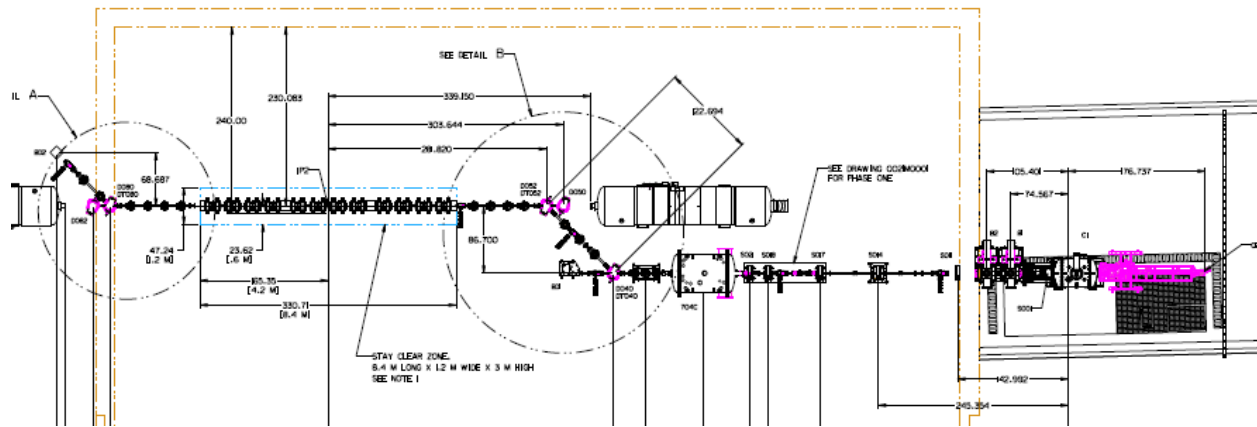
- Gun
    - Max. Voltage 2 MV
    - Max. RF power to gun is 2 kW
    - Max. power to the beam is 0.8 kW
    - Superconducting
- Buncher Cavities (2 cavities)
    - Max. Voltage 300kV each
    - Max. power delivered to each cavity 25kW

- No net power delivered to beam for routine operations
- Maximum of 0.6 MeV addition to beam energy under abnormal conditions
- Warm cavities
- Beam dump (G5 beam dump)
- Linac **not** in place (will eventually increase beam energy to 22 MeV)

The layout of components for the tests during RHIC run14 is shown in Figure 1. The preliminary layout for the completed project for RHIC run15 is shown in Figure 2 for reference. The two warm buncher cavities and the superconducting gun are located in their final positions. The 702 MHz Linac will not be installed until after RHIC run 14. The beam dump is located in a temporary location and will be moved next year to a location after the first dipole as shown in Figure 2. The outline of the tunnel and shielding is shown in Figure 1.
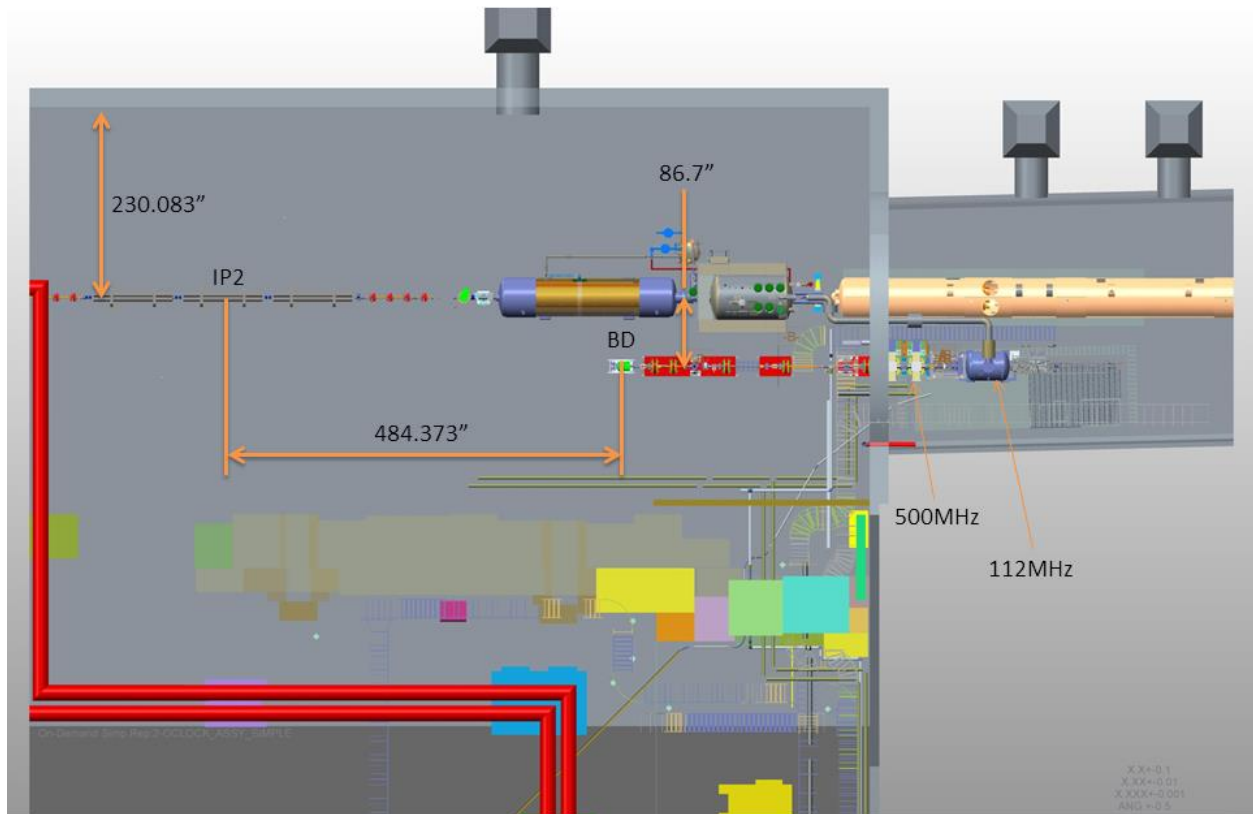

Figure 1: Layout for the tests during RHIC run 14. The temporary location of the G5 beam dump is shown as BD. The two 500 MHz cavity locations and the 112 MHz superconducting gun are shown in the tunnel along the D0 cryostat.

Figure 2: Preliminary layout of the complete project.

Shielding and Routine Radiation Dose Rates

The location of beam losses both routine and under fault conditions must be considered in estimating the risk for potential exposure exterior to the shielding. The routine loss point is dominated by the G5 beam dump. 100% of the beam generated by the gun is expected to be transported to the beam dump. Other routine losses can be caused by intrusive instrumentation. There will be two profile monitors and a pepper pot located in the beam between the gun and the dump. However, these are relatively thin targets for the beam. The potential dose rates outside the shielding are covered by wither the routine or beam fault losses discussed below.

The overall layout of 2 O'clock is shown in Figure 3. The fence between building 1002B and the shielding prevents personnel access. This access restriction during RHIC operations is due to the large penetrations in the shielding for the cryo-piping and other utilities.

Figure 3: Layout of the 2 O'clock IR with the fences. The berm and IR concrete roof are enclosed in one fence and there is a small fence between building 1002B and the shielding. The upgraded equipment port is not depicted in this drawing.

The shielding drawings[1] were used to evaluate potential radiation levels outside the IR due to operations of CeCPoP. Figure 4 shows the shield wall at beam height. It has section views indicated on the print. Figure 5 shows three of the sections that are in the region of the CeCPoP that will be operational during RHIC run14. Section F will be used to estimate the potential dose rate through the shielding during RHIC run14.
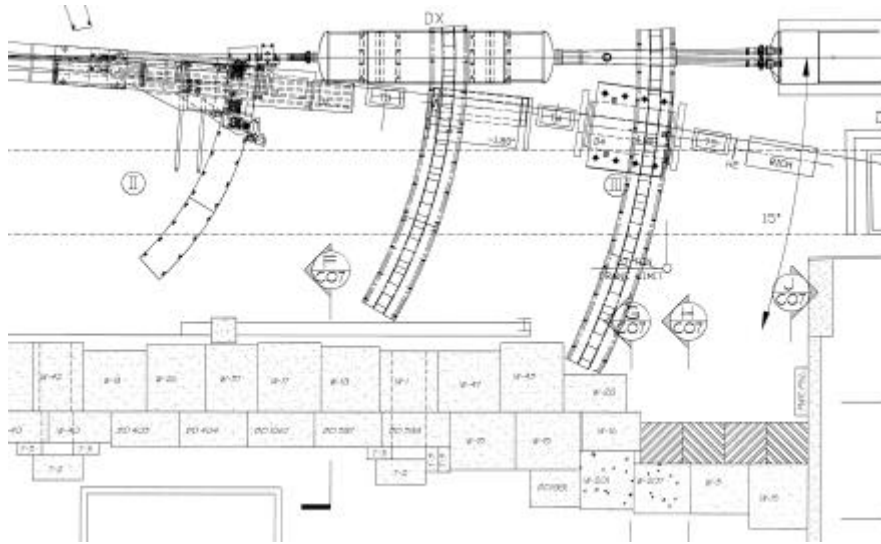
Figure 4 : Plan view of the shielding wall at beam height (elevation 69'2''). The section of wall near the entrance port is not shown. The temporary beam dump for RHIC run14 is located about mid-way along the DX magnet (see Figure 1).
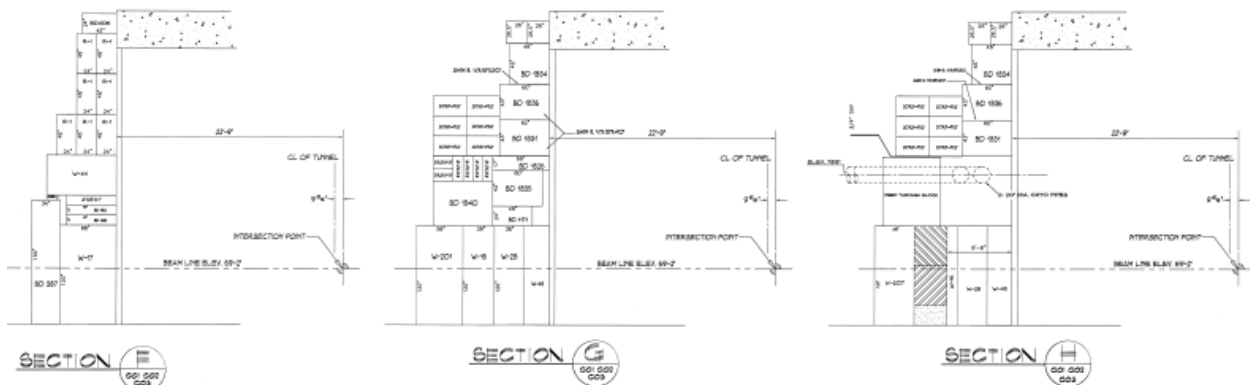
Figure 5 : Three section views of the shielding. Only section F is in an area that is allowed to be occupied by personnel while RHIC operates. The roof thickness is uniform across the intersection region (IR).

[1] See the drawing archive at http://dwg-server.c-ad.bnl.gov/eng-arch/rhic.htm and look at the list of areas near 2 O'clock.

Some relevant geometric parameters are:

Table I: Shielding Parameters at IR2

Location	Distance to outside (m)	Thickness of Shield (m)	comment
Roof	7.65	1.15	Light concrete
Side wall	7.8	2.6	Light concrete
Interior B Alcove gate	300	0	No line of sight

For Run14 operations of CeCPoP essentially all the 2.0 MeV electron beam will be transported into the beam dump. This steel beam dump was simulated[2] for beam tests at ERL. The results of that analysis can be used to examine the potential routine radiation dose rates outside the shielding. For routine losses at the beam dump the displacement of the dump to the various locations in the beam direction will be ignored. This will render the calculations conservative and make it trivial to scale to maximum beam fault along the beam line.

The other source of radiation from CeCPoP is the generation of x-rays from the gun and the warm cavities. The dose rate for the warm cavities of 20 rads/hr at a meter is less than the transverse dose rate of the beam dump, which is 34 rads/hr at a meter

The beam energy used in the ERL analysis was 3.5 MeV which means that is overestimates the routine dose rates at 2.0 MeV. The maximum possible power that can be delivered to the gun is 2kW. It is expected that the maximum beam power will be 0.8 kW. For this analysis the electron beam is assumed to have a power of 2kW and this will be used to scale the dose rates. A TVL of 55 g/cm^2 for light concrete will be used where it is necessary to scale to larger shielding thickness. The estimated dose rates at various shield locations are:

Table II: Routine Dose rates for 2kW of Beam

Location	Dose rate (mrad/hr)	Comments
IR roof	$3.9*10^{-2}$	Locked fence
IR side wall-beam elevation	$2.6*10^{-8}$	Controlled Area
Sector 1 internal gate	$3.6*10^{-2}$	0.4 used for air attenuation and 0.03 for one scatter
Sector 3 internal gate	Less than $3.6*10^{-2}$	Backwards direction so less than sector 1 gate

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[2] http://www.c-ad.bnl.gov/esfd/RSC/Memos/G5%20Beam%20Dump%20Simulation.pdf

Penetrations

The radiation from the beam dump or other source can impinge of any of the penetrations that exist in the area. The possible dose out these penetrations will be estimated from simple techniques or using Monte Carlo techniques.

There are two cableway penetrations that exit the IR at ground level. Each has a four-foot vertical rise to for a two-legged labyrinth. The cableway penetrations can be seen as the dashed lines in Figure 4. The attenuation out of these penetrations can be estimated using the method of albedo coefficients[3]. The dose rate out the cable port[4] exit is 0.6 mrads/hr. The cableway penetration further downstream of the dump should be substantially[5] smaller.
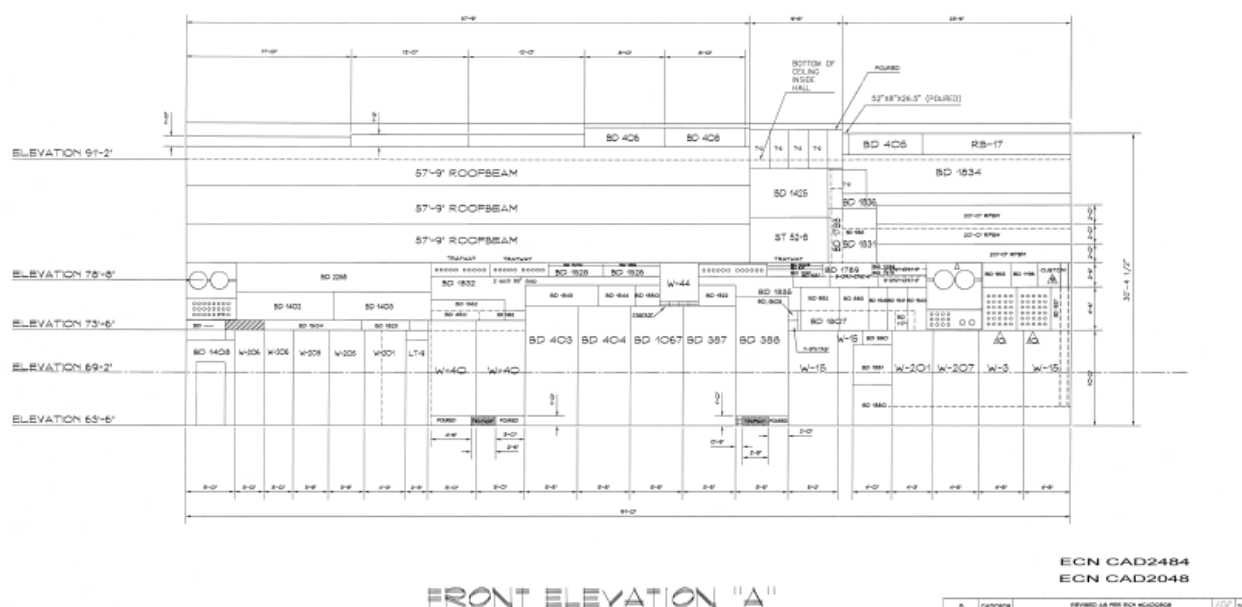
Figure 6: An elevation view of the IR2 shielding. The equipment portal has not been updated on this drawing. The various penetrations high on the shielding are shown in this view.

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[3] NCRP Report No. 144, Radiation Protection for Particle Accelerator Facilities, Dec. 31, 2003; National Council on Radiation Protection and Measurements. See section 4.11.2
[4] The punch-though out the rear block of the cable port would produce 0.06 mrads/hr at ground level.
[5] The distances are farther and an additional reflection is required.

A series of 4 inch diameter ports in the form of buss blocks exist at an elevation of 5 meters above the ground. The potential dose can be estimated using simple techniques[6]. The estimated dose rate is 5 mrads/hr. A calculation was conducted using MCNPX[7] 2.7c and the attenuation of the 4 inch diameter port is $7.0*10^{-5}$. The dose rate one foot from the port exit is 0.064 mrads/hr.

There are two personnel labyrinths that are used to access the IR and the 3 O'clock sector including the IR. The main IR labyrinth is near the equipment portal in the shielding on the 1 O'clock side of the IR. The opening of the labyrinth is shadowed from the dump by the side wall shielding (see Figure 3). The estimated dose out the labyrinth gate for 2kW of beam on the dump is less than 0.01 mrads/hr, with the side wall shadowing ignored.

The personnel labyrinth from the tunnel to building 1002A is shown in Figure 3. The estimated attenuation of labyrinth entrance dose to the gate from the possible CeCPoP sources is 10^{-7}. This is more than sufficient to limits dose rates at the gate to acceptable levels. There is a chipmunk near the gate but it will not interlock the RF and electron beam. It will alarm MCR that there is detected radiation at the gate.

The IR has two ventilation shafts on the rear of the IR wall. They exit the berm inside the locked-fenced area that encloses the IR roof and adjacent berms. The largest is an emergency ventilation shaft with a vertical shaft diameter of 48 inches that is feed by two horizontal 42 inch diameter shafts. The smaller vent has a 30 inch diameter and is intended for gas vent pipes, if needed. The off-set along the beam direction will be ignored in making simple dose rate estimates for these shafts. The dose rate from the transverse radiation from the beam dump at 2 kW is estimated to be $2*10^{-3}$ mrads/hr for the large vent and $0.5*10^{-3}$ mrads/hr for the small shaft.

The tunnel has two ventilation shafts upstream of the potential x-rays sources. The shafts are identical except for their location along the tunnel direction. The center of these shafts is close to beam height so that the attenuation will be treated as a single 90 degree bend. The shielding provided by the D0 cryostat will be ignored. These 42-inch diameter shafts are estimated to have an attenuation of $8*10^{-6}$ for a source intensity evaluated at 1 meter from the CeC PoP beam axis. For a 20 rad/hr at a meter x-ray source[8] the potential dose rate at the shaft exit of the berm is 0.16 mrads/hr.

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[6] A.H. Sullivan, <u>A guide to Radiation and radioactivity Levels Near High Energy Particle Accelerators</u>, Nuclear Technology Publishing (1992). See figure 2.26.
[7] MCNPX version 2.7C was used for the calculations in this report. D. B. Pelowitz et al., "MCNPX 2.7.C Extensions", LA-UR-10_00481, March 5, 2010. The calculation used 1 MeV photons as the source.
[8] Source based private communication with A. Zaltsman on potential dose rates from the warm cavities.

There are a group of small pipes that exit the tunnel ceiling. These pipes have dog-legs in them so that a minimum of two scatters in the pipe are required for radiation to exit the berm. It has been assumed that they are six inches in diameter[9] and the shortest pipe has a 5 m vertical rise. The exit dose is estimated to be $7*10^{-9}$ of the entrance dose. For any potential CeCPoP source these pipes are not an issue. The pipes are inside the berm area that is enclosed by the locked fence.

A two-foot diameter HVAC vent is located in the tunnel upstream of the CeCPoP gun. It connects the tunnel to the HVAC equipment located in building 1002A. There is a horizontal shift between the entrance port in the tunnel and the exit port in Bldg. 1002A by 1.35 diameters. This shift is not documented[10] in the shielding prints. If the internal shift is ignored then the dose rate out the vent in 1002A from the warm cavities at 20 R/hr at a meter would be 0.02 mrads/hr. With the horizontal shift of 1.35 diameters an additional reduction of 10^{-3} is likely. Therefore, this vent is not expected to be problem.

The cryo-pipes exit the tunnel in two locations at the IR. For the initial CeCPoP tests the relevant penetrations to consider are the ones near Bldg. 1002B. The center of these two-foot diameter penetrations are at an elevation of 69' 8'', which corresponds to 15' 2'' above the ground. The area outside the shielding is inside a locked fence (see Figure 3). The penetrations on the 3 O'clock side of the IR can be illuminated by the CeCPoP warm cavities or electron beam loss. MCNPX was used to estimate a dose rate of 7.7 mrads/hr. This result was evaluated one foot from the shielding directly over the port from the beam dump[11]. The substantial material of the vacuum jacketed cryo-piping was ignored. The calculation was expanded so that point detectors could be placed at locations along the locked fence and at the center of the cryo-pipe at building 1002B. The transverse distance from the center of the cryo-pipe to the fence is 4.1 meters[12]. The building wall of 1002B is 7.34 meters from the shielding. The highest dose rate at the fence was at building 1002B and is 0.009 mrads/hr. The dose rate at the building skin and at the center of the cryo-pipe is 0.03 mrads/hr. For routine operations locations outside the secured fence are more than acceptable.

A similar calculation was conducted assuming an empty one-foot diameter hole in the shielding. The dose rate for the beam dump was estimated to be 0.9 mrads/hr. The ratio of the two results is in good agreement of the scaling given in footnote 6. The smaller holes in the area will result in much smaller dose rates than those estimated for the open cryo-pipe penetration.

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[9] The drawing was not specific enough to determine if they were 4 inches or 6 inches.

[10] This shift has been verified by measurements. A request to update the drawing has been made. This labyrinth is assumed to be a three legged labyrinth.

[11] The estimated was conducted assuming 1.0 MeV gammas. The longitudinal shift of the beam dump to the cryo-ports was ignored. This location is blocked by the cryo-piping.

[12] An elevation of five feet above the ground has been used and the measured horizontal distance of 2.7 m.

Maximum Beam Fault Dose Rates

Radiation from beam striking components in the beam line can cause potential dose rates higher than those from the beam dump. The G5 beam dump provides about six inches of shielding in both the forward and transverse direction. The TVL for Fe is 60 gm/cm^2 so that if the beam should scrape along the beam transport the dose rates may be a factor of 100 higher than those from the beam dump. To provide a better estimate the of the maximum possible transverse dose rate the calculations of footnote 2 were conducted for targets with smaller radii to remove self-shielding effects. A 1 mm radius copper rod has dose rates of $5.22 * 10^{-17}$ rads/(e-hr) at 3 meters which are 2.09 times higher than reported in footnote 2. This target may be a good representation of the beam striking the beam pipe wall. For the maximum transverse dose rates outside the shielding from full beam faults the routine radiation levels can be multiplied by a factor of 174.

The transverse dose can be checked with the thick target data[13]. 2.5 MeV electrons with 2kW of beam power produce dose rates of 12,000 rads/hr at a meter. This is in good agreement with the MCNPX source terms used above which corresponds to 8500 rads/hr at a meter.

Conclusions

We can compile the results for routine dose rates and beam fault dose rates for the possible gun and RF testing for RHIC run14. The results are given in Table III below. It is clear that none of the routine dose rates create an issue for personnel exposure. There are several dose rates for full beam faults that exceed 5 mrads/hr. If the areas where access is not permitted are removed from the list then only a few locations can exceed 5 mrads/hr. The dose rate at the cableway exit could easily be reduced with a small amount of shielding placed at the entrance of the cableway inside the IR. The 6.3 mrads/hr for a fault at the sector 1 gate is most likely well below that level and either more careful calculations can be conducted or credit for administrative limits could be used. Note that if the beam power of 800 W is used the estimated dose rate at the gate is reduced to 2.5 mrads/hr.

It is recommended that the RSC consider allowing the beam test in June with no limits on the beam current. The cableway should be modified for the test and additional consideration given to the potential dose rates at the internal gate in sector 1.

The committee should consider recommending that the Department request an exemption for the ARR requirement of the ASO to allow beam testing of the CeCPoP gun during RHIC run14.

The operation of the gun and the warm cavities will require that the changes to the 2 O'clock PLS PASS systems are completed so that personnel are properly protected from these new

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[13] See reference in footnote 3 Figure 3.5.

sources of radiation. The interlocks will be discussed at the RSC meeting planned for March 24, 2014.

Table III: Dose rates at various locations for 2kW of electron beam

Location	Routine Dose Rate mrads/hr	Beam Fault Dose Rate mrads/hr	Comments
Roof	$2.9*10^{-2}$	6.8	Locked area
Side wall	$2.6*10^{-8}$	$4.5*10^{-6}$	
Sector 1 gate	$3.6*10^{-2}$	6.3	Potential shielding from beam dump ignored
Sector 3 gate	Less than $3.6*10^{-2}$	Less than 6.3	Expected to be much lower
Cableway	0.6	104	Could be blocked for test or better calc.
4-inch holes in buss blocks	0.064	11.1	15 feet above ground access not permitted
Labyrinth (1 Oclock side of IR)	0.01	1.7	
Labyrinth (to bldg. 1002A)	$4.3*10^{-5}$	0.08	Routine uses wam cavities—fault uses beam Chipmunk at gate
IR emergency ventilation shaft	$2*10^{-3}$	0.3	Locked area
IR gas vent	$5*10^{-4}$	0.09	Locked area
Tunnel ventilation shaft	0.16	7.5	Routine source is warm cavity —locked area
HVAC shaft	.00002	.0009	Routine source is warm cavity
Cryo-pipe bldg. 1002B	0.03	5.2	Cryo-pipe material ignored
Cryo-pipe-fence	0.009	1.6	Cryo-pipe material ignored

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